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ALFALFA HI Content and Star Formation in Virgo Cluster Early-Type Dwarfs

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Abstract.

Early-type dwarfs dominate cluster environments, yet their formation and evolutionary histories remain unclear. The ALFALFA (Arecibo Legacy Fast ALFA) blind survey is providing a census of HI in galaxies of all types in a range of environments. Here we report on ALFALFA results for Virgo Cluster early-type dwarfs between declinations of 4 and 16 degrees. Less than 2% of the Virgo early-type dwarf population is detected, compared to 70-80% of the Im/BCD dwarf population. Most of the dwarfs detected in HI show evidence for ongoing or recent star formation. Early-type galaxies with HI tend to be located in the outer regions of the cluster and to be brighter. Early-type dwarfs with HI may be undergoing morphological transition due to cluster environmental effects.

1 Introduction

Early-type dwarfs are often assumed to be lacking in HI gas and star formation. Models often picture their star formation history as a single burst early in the history of the Universe. Yet a subset of early-type dwarfs shows signs of relatively recent star formation, as revealed by stellar populations, star formation, and gas content (e.g., Conselice *et al.* 2003; Lisker *et al.* 2006, 2007; Grossi *et al.* 2008). The detection of recent star formation in some systems suggests that at least some early-type dwarfs have formed by transitioning from another galaxy class, e.g., a later-type spiral or dwarf that loses its gas as it enters the hostile environment of a galaxy cluster, or perhaps a gas-poor object accretes gas from another object. Lisker *et al.* (2007) find that approximately half of the early-type dwarfs in Virgo belong to an unrelaxed population that could be associated with recently infalling galaxies.

Previous studies have attempted to quantify the HI gas content of early-type dwarfs (e.g., Conselice *et al.* 2003), but have been limited by small samples and heterogeneous observations. The Arecibo Legacy Fast ALFA (ALFALFA) Survey, a sensitive blind survey of the Arecibo sky (Giovanelli *et al.* 2005), is providing a complete and unbiased view of HI content and structures in various environments to $z=0.06$. Included in the survey is the entire Virgo cluster region, for which ALFALFA has a limiting HI mass sensitivity of $\sim 2.0 \times 10^7 M_\odot$.

Figure 1. (a) Locations of dE/dS0 galaxies detected by ALFALFA in the declination range 4-16 degrees, superposed on a ROSAT map of the Virgo Cluster (Boehringer *et al.* 1994). The approximate locations of the M, W', and W clouds (Binggeli, Popescu, & Tammann 1993) are indicated. Solid symbols denote dE/dS0 with H α emission. (b) Log M_{HI}/L_B vs M_B for detected dwarfs. The dotted line shows the completeness limit for a galaxy with an HI mass of $2.5 \times 10^7 M_\odot$ at the Virgo distance. In both figures, four dE/dS0 with uncertain HI detections are separately indicated.

2.1 HI

ALFALFA HI detections in the Virgo Cluster between the declinations of 4 - 16 degrees (e.g., Giovanelli *et al.* 2007; Kent *et al.* 2008) were compared with the Virgo Cluster Catalog (VCC: Binggeli, Sandage, & Tammann 1985; Binggeli, Popescu, & Tammann 1993) to identify galaxies classified as dwarfs. A total of 17 or 1.6% of the Virgo dE/dS0 in this declination range were detected by ALFALFA. Four of these are uncertain due to poor signal-to-noise and/or interference from M87 or radio noise. In contrast, Im and BCD galaxies are detected at a rate of 68% and 79%, respectively.

The HI profiles of the detected dE/dS0 are mostly singly-peaked. Most have velocity widths (uncorrected for inclination) in the range 30-60 km s⁻¹. The median HI mass is $3.5 \times 10^7 M_{\odot}$. This is 2.2 times smaller than the median HI mass of Virgo Im galaxies (and ~ 2 times the ALFALFA detection limit at the Virgo distance).

Figure 1a shows the distribution of detected dE/dS0 superposed on the Boehringer *et al.* (1994) ROSAT map of the Virgo Cluster. Most are located in the cluster outskirts, with several in the direction of the M Cloud. The median distance from M87 of dE/dS0 with HI is 4.3° (1.3 Mpc for an assumed Virgo distance of 16.7 Mpc), compared to a median distance of 3.2° (0.9 Mpc) for the general dE/dS0 population.

The dE/dS0 with HI are 3 times brighter in the median than the genedominant mechanisms at work will require a dwarf elliptical population (99.8%

significance). This may be partially due to selection effects, since fainter dwarfs with a similar fraction of HI per unit luminosity would fall under the detection limit for ALFALFA at the distance of Virgo. Considering only galaxies with $M_B < -16$, we find that 7% (5/71) of dE/dS0 are detected.

Figure 1b shows M_{HI}/L_B as a function of M_B for Virgo dwarfs with HI. The median M_{HI}/L_B of dE/dS0 with HI is 0.27, about half that of Virgo Im or BCD. Compared to more isolated dwarfs (not shown), we find that Virgo dwarfs extend to lower M_{HI}/L_B .

2.2 H α

H α images were obtained for 12 early-type dwarfs with HI at the CTIO 0.9m (SMARTS), the Wise Observatory 40-inch, the WIYN 0.9m (courtesy J. Salzer), and from the Goldmine online database (Gavazzi *et al.* 2003). 75% (9/12) of early-type dwarfs show H α emission. The median equivalent width is about 5 times smaller than the value for Im galaxies. In most cases, the emission is centrally concentrated, extending about half as far in the median as that of Im galaxies.

3 Comparison to Previous Results

Conselice *et al.* (2003) reported 7/48 (15%) Virgo dE/dS0 sample detected in HI. Six of the detected galaxies are within our declination range. Two, the brightest and third-brightest, are not detected by ALFALFA and were likely confused in previous observations. Three detections are reproduced by ALFALFA with comparable masses, although one of these, VCC 31, is classified ‘?’ in the VCC and is not counted here as dE/dS0. A fourth is a marginal detection by ALFALFA requiring followup confirmation (not counted as a detection in this paper).

Lisker *et al.* (2006, 2007) present an extensive study of 413 Virgo dE/dS0 with $M_B < -13.1$, defining sub-types based on morphological features. We detect 7 of these galaxies in HI. Four are dE(bc) or dE with blue center, comprising 17% of the dE(bc) class. Three of these also show H α emission. The other four galaxies in the Lisker *et al.* sample have four different sub-type classifications. However, we find no HI detections among galaxies classified as dE(di), or dE with disk feature.

vanZee *et al.* (2004) find that about half of a sample of 16 Virgo dE/dS0 galaxies show significant rotation, with amplitudes of 20-30 km s⁻¹. None of the galaxies in their sample is detected in HI by ALFALFA.

4 Summary

The ALFALFA survey is providing a homogeneous survey of HI content in Virgo Cluster dwarf galaxies. Observations to date reveal that fewer than 2% of Virgo dE/dS0 dwarfs have HI reservoirs. Those that do typically have weak H α emission indicating ongoing star formation. The H α morphologies suggest that gas has been preferentially removed from the outer galaxy and/or funneled into the central regions. Virgo dwarfs with HI classified as dE/dS0 could be transitional objects, evolving from gas-rich progenitors subjected to cluster environmental ef-

fects. Aperture synthesis observations will be helpful in distinguishing dominant mechanisms.

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